An Experimental Study of Pressure Coefficient and Flow Using Sub Sonic Wind Tunnel
The Case of A Circular Cylinder

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Abstract— In this research paper we will carried out the experimental investigation of forces and pressure on circular cylinder in wind tunnel at different wind speed. These experiments taken out at constant interval of angle. Experimental exercises are designed and tested in a subsonic wind tunnel to study pressure distribution around circular cylinder. The concept of the pressure coefficient is introduced and its use in the literature is illustrated and explained.

Keywords— Circular cylinder, Coefficient of pressure, Cp Vs theta graph, D Alembert paradox,

I. INTRODUCTION
Circular cylinders with the fluid flow over the surface have been a topic of research for over a hundred years, for their practical and fundamental importance. Practically it is seen that circular cylinders are much more used in many engineering and industrial applications such as bridges, mills, towers, buildings, platforms and heat exchangers. There are many studies have been done with two dimensional and three dimensional flow around circular cylinders. That is free of end effects. The primary aim of this thesis is to study experimentally, the pressure and their coefficient develops at the different points of circular cylinder at different different angles. The graphs and structure of pressure developed at different velocities of air. All these experiment are done in laminar flow of air considered. For this study of fluid flow, test section of wind tunnel is used. Many exercises can be designed and tested in the fluid mechanics laboratory to study pressure distribution around the bluff bodies in the wind tunnel like that circular cylinder, solid sphere, buildings, pipes rods and air jets.

Stream line is a path traced out by a mass less particle moving with fluid flow. Velocity is tangent to stream line at every point mass does not cross stream line. We can define as also a stream line is path traced out by a mass less particle as it moves with flow. It is easiest to trace stream line if we move along the body.

The mass contained between any two stream lines remain constant throughout the flow field. We can use Bernoulli equation to relate the pressure and velocity along the stream line since no mass passes through the surface of cylinder .the surface of object is a stream line.

According to Bernoulli equation

\[ \frac{p_{\text{atm}}}{\rho_{\text{air}}} + \frac{1}{2} V_0^2 + g z_0 = \frac{p_{\infty}}{\rho_{\text{air}}} + \frac{1}{2} U_0^2 + g z_{\infty} \] (1)

\[ p_{\text{atm}} - p_{\infty} = \frac{1}{2} \rho_{\text{air}} U_0^2 \] (2)

\[ U_\infty = \sqrt{\frac{2(p_{\text{atm}} - p_{\infty})}{\rho_{\text{air}}}} \]

If water manometer is used in atmospheric pressure

Then-

\[ U_\infty = \sqrt{\frac{2 p_{\text{water}} g (\Delta h)}{\rho_{\text{air}}}} \]

\[ U_\infty = \sqrt{\frac{2 \times 1.03 \times 10^3 \times 9.81 \times \Delta h}{1.225}} \]

\[ U_\infty = 129.39 \sqrt{\Delta h} \] (3)

It is called free stream velocity

II. D ALEMBERT PARADOX
D’Alembert’s paradox applied to a cylinder states that the net pressure drag exerted on a circular cylinder that moves in an in viscid fluid of bags extent is identically zero. This result is proved below.
Consider the steady flow of a frictionless and incompressible fluid from left to right over a stationary circular cylinder of radius \( r = a \). If the flow is horizontal and uniform at infinity with magnitude \( U \) and pressure \( P \) there, then, its velocity \( V \), in the vicinity of the cylinder is given in cylindrical coordinates \((r, \theta)\) by:

\[
\vec{V} = U \left[ \left( 1 - \frac{a^2}{r^2} \right) \cos \theta \right] \hat{r} - U \left[ \left( 1 + \frac{a^2}{r^2} \right) \cos \theta \right] \hat{\theta}
\]

(4)

Where \( \hat{r} \) and \( \hat{\theta} \) are unit vectors in the \( r \)-and \( \theta \)-directions, respectively. From Eq. (4), the magnitude of the velocity at any point is given by:

\[
V = U \left[ 1 + \left( \frac{a^2}{r^2} \right)^2 - 2 \left( \frac{a^2}{r^2} \right) \cos 2\theta \right]^{1/2}
\]

(5)

On the surface of the cylinder, where \( r = a \), the magnitude given in Eq. (5) becomes:

\[ V = 2U \sin \theta \]

The pressure, \( p_c \), at a point of coordinates \((a, \theta)\) on the surface of the cylinder is found by using Bernoulli’s equation along the streamline through that point. It is given by:

\[ p_c = p_\infty + \frac{1}{2} \rho U^2 \left( 1 - 4 \sin^2 \theta \right) \]

(6)

Since this flow has no friction, the total drag is due to pressure and it can be obtained by evaluating the following integral over the surface of the cylinder:

\[ F_D = - \int_A p_c \, dA \cos \theta, \]

(7)

Where \( p_c \) is given by Eq. (6), and \( dA \) is an element of the surface area on the surface of the Cylinder given by \( dA = aL \, d\theta \), with \( L \) being length of the cylinder. Evaluation of the integral in Eq.(7) around the circumference of the cylinder yields:

\[ F_D = aL \left[ \frac{2}{3} \rho U^2 \cdot \sin^3 \theta - \left( p_\infty + \frac{1}{2} \rho U^2 \right) \sin \theta \right]_{\theta = \pi}^{\theta = \pi/2} \]

(8)

Which is identically zero, thus, verifying D’ Alembert’s paradox. Historically, this result was called a paradox because real fluids, which are all viscous, do, in fact, exert drag forces on cylinders moving in them. This paradox is an excellent stepping stone to use to explain some features observed in the flow of viscous fluids around, or over immersed, objects of all kinds.

What happens in viscid flow is that the pressure decreases continuously on the upstream half of the cylindrical surface in such a way that the drag force on that half is not zero. It can be verified that it is given by:

\[ F_{D\theta = \pi/2} = 2aL \left[ \frac{5\rho U^2}{6} - P_\infty \right] \]

(9)

However, pressure subsequently increases continuously on the downstream half of the cylinder in such a way that the drag force on it is the exact opposite of that developed over the upstream half. It can also be verified that it is given by:

\[ F_{D\theta = 3\pi/2} = 2aL \left[ P_\infty - \frac{5\rho U^2}{6} \right]. \]

(10)

Thus, for the whole cylinder, then, the two opposing drag forces combine to give zero, demonstrating that all the pressure lost on the upstream half is recovered over the downstream half of the cylinder. This is what makes the net drag force over the whole cylinder zero. It was discovered that this paradox was made possible by the absence of friction [12]. Indeed, such total recovery of pressure on the downstream half of the cylinder does not occur in a real fluid, no matter how low its viscosity.

### III. Pressure Coefficient

In order to compare the variation of pressure around a bluff body for a variety of flow conditions, it is conventional to use a dimensionless ratio called the pressure coefficient \( C_p \), which compares the pressure on the surface of the cylinder, \( p_c \), to that at infinity, \( p_\infty \). It is defined by:

\[ C_p = \frac{p_c - p_\infty}{\frac{1}{2} \rho U^2} \]

(11)
When flow is in viscid, we combine Eq. [6] and Eq. [9]
to get:

\[ C_p = 1 - 4 \sin^2 \theta \]  
(12)

Unfortunately, a closed-form expression of \( C_p \) as a function of \( \theta \), similar to that shown in Eq.[12], cannot be
obtained analytically when the fluid is viscous. This is
because neither the pressure distribution nor the velocity is
known at every point along the surface of the cylinder.
However, one can measure the pressures at many points
along a chosen cross section of the surface of the cylinder
experimentally, compute \( C_p \) point by point using Eq.[11],
and subsequently plot the results as a function of the
position, \( \theta \), of each point where measurements were made.

When such data have been plotted, the shape of the
resulting curve and the magnitudes of the pressure
coefficients at different points can be compared to those of
the graph of Eq.[12], to determine the effects of viscosity
and the Reynolds number. The theoretical value of
coefficient of pressure graph shown in fig 2.

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<th>22.4m/s</th>
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Fig2

![Cp vs Theta Graph](image1)

![cp vs theta graph](image2)
IV. RESULT AND DISCUSSION

The graph of fig1 and fig2 describes the relationship of parameters related to coefficient of pressure and circumferential distance theta. These experiments are carried out for Reynolds number $0.62 \times 10^5, 0.76 \times 10^5, 0.88 \times 10^5, 1 \times 10^5, 1.2 \times 10^5$.

From the graph fig2 the theoretical values and graph fig 3 practical values of coefficient of pressure are shown. From the comparison point of view it can be seen that the values of coefficient of pressure at 0 and 360 degree are close to 1 practically and 1 theoretically. These are 0.833, 0.81, 0.80, 0.75. These values shows that the practical is in right way. Some atmospheric, experimental, technical's well as instrumental problems are noticed during the experiment. By solving these problems the results are taken much more accurate. In the experiment the result found that in each value of velocity of air the coefficient of pressure decreases with increase the angular distance 0 to 90 after that again increases up to 180 degree. If the cylinder surface divided into two halves, upper and lower. In upper half and lower halves graph meets same theoretically. The graph meets same practically. 90 degree and 270 degree values are close to 3.

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